

## Cold-Induced Vasodilatation Onset and Manual Performance in the Cold

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This study is an investigation of manual dexterity capabilities during whole-body cold exposure as a function of time to vasodilatation during local cooling. Thirty male subjects were divided into three equal groups on the basis of the time for a 3°F (1.7°C) rise in index finger temperature during immersion of the hand in 4.4°C water: <450 sec group, 450-900 sec group, and >900 sec group. Subsequently, each subject was exposed to ambient temperatures of 15.6° and -6.7°C for three hours while performing a battery of six manual tasks bare-handed. Manual performance on all tasks was affected adversely at the -6.7°C ambient and worsened with continued cold exposure. The drop in performance on three tasks involving skilled movements of the wrist and fingers was greatest for the <450 sec group. Within the limits of the present study, the early onset of vasodilatation in local cooling *per se* appears to be associated with initially superior performance and subsequently inferior performance on specific manual tasks with increasing durations of whole-body cold exposure.

### 1. Introduction

The purpose of the present study was to investigate manual dexterity capabilities during whole-body cold exposure in individuals who differed in the time of vasodilatation onset during immersion of the hand in cold water. When the body is warm, the temperature of a finger immersed in cold water oscillates, decreasing due to vasoconstriction then increasing indicating vasodilatation (Lewis 1930). In addition to blood flow and digital temperature changes, the oscillations between vasoconstriction and dilatation during local cooling are accompanied by changes in subjective response and tactile discrimination. During the vasoconstrictive phase, the subject experiences pain and eventual numbing of the immersed extremity. With the onset of dilatation, there is a rapid disappearance of pain and a return of touch and pressure sensations as the extremity rewarms (Shepherd 1963, pp. 101-126). The Mackworth *V*-test threshold for tactile discrimination has been found to vary in phase with the oscillation between constriction and dilatation with greater sensitivity during the latter (Provins and Morton 1960).

Based upon studies of both intra- and inter-individual acclimatization, the disappearance of pain and the return of tactile discrimination associated with dilatation appear to be adaptive to survival during cold exposure. Decreases in the time to vasodilatation and increases in the skin temperature at which dilatation occurs have been obtained as a result of repeated exposures of either the hands or the feet to cold water (Yoshimura and Iida 1952, Glaser and Whittow 1957) or of the whole body to cold air (Carlson *et al.* 1953). Similar differences in time to onset of and skin temperature at vasodilatation were also obtained when such acclimatized individuals as Eskimos, Gaspé fishermen, and Alaskan natives were compared with unacclimatized Caucasians during whole-body exposure to cold air or to local cooling of an extremity in cold water (Leblanc 1966, Meehan 1957). Such changes in cold-induced vasodilatation

(CIVD) may result in increased body heat loss, but the changes also serve to protect the extremities from cold injury and result in superior tactile discrimination. In addition to differences in CIVD, acclimatized individuals have shown smaller increases in blood pressure (Leblanc 1966) and greater blood flow fluctuations (Brown and Page 1952) than controls during local cooling in cold water, together with greater increases in metabolic heat production and lesser decreases in hand skin temperature during whole-body exposure to cold air (Meehan 1957).

Differences in the time to onset of vasodilatation have also been found among unacclimatized individuals apparently from the same population. Teichner grouped individuals on the basis of CIVD onset and compared them with regard to decision-making speed in a risk-taking situation (1965) and vigilance performance during exposure to a 12.9°C ambient temperature condition (1966). Vasodilatation was defined as a 3.0°F (1.7°C) digital temperature increase during immersion of the hand in 1.1°C water. In the risk-taking study, subjects were divided into groups of those who vasodilated before and those who vasodilated after 400 sec of the 20 min immersion period had elapsed. As both potential risk and gain increased, the delayed vasodilators first increased and then decreased their speed of decision-making, whereas the speed of the early vasodilators increased continuously (Teichner 1965). The two groups for the vigilance study were comprised of those subjects who vasodilated in less than 400 sec and those who did not vasodilate within the 600 sec immersion period (Teichner 1966). Vasodilators were found to maintain slightly higher digital, rectal, and estimated mean skin temperatures prior to and during local cooling. Nonvasodilators showed better detection performance on the vigilance task than vasodilators at 26.9°C and poorer performance at 12.9°C. Teichner attributed the findings to differences in arousal between vasodilators and nonvasodilators in that, for nonvasodilators, exposure to cold resulted in overarousal and poorer performance. At the lower temperatures, the digital temperatures of vasodilators first decreased and then increased indicating the occurrence of dilatation, whereas those of the nonvasodilators decreased continuously with time. The rectal temperatures of nonvasodilators were slightly lower than those of vasodilators at 12.9°C and their mean skin temperatures were initially slightly higher, but declined over time to become lower than those of vasodilators. During exposure to 26.9°C, the nonvasodilators maintained slightly lower digital and mean skin temperatures and higher rectal levels than did the vasodilators.

The present study of individuals who differed in time to onset of vasodilatation was concerned directly with the relationship between time of vasodilatation onset and digital temperature. It was assumed that, as in acclimatized individuals, early onset of vasodilatation would be related to higher digital temperatures and that higher digital temperatures would result in better manual performance during whole-body cold exposure. While previous attempts to correlate performance and digital temperature during cold exposure either have not been notably successful (Teichner 1957) or have shown the relationship to be limited to specific recording sites, manual tasks, and parameters of cold exposure (Lockhart and Kiess 1971), there is evidence relating digital surface temperature and manual performance during cold exposure. Dusek (1957) found (1) a definite decrement in performance, (2) an even larger

decrement and the occurrence of pain reports, and (3) an almost complete loss of tactual discrimination when hand skin temperature dropped below  $15.6^{\circ}$ ,  $10.0^{\circ}$  and  $4.4^{\circ}\text{C}$ , respectively. Lockhart *et al.* (in press) found the initial impairment of manual performance and the extent of subsequent impairments to vary as a function of finger surface temperature, cooling rate, and manual task.

Based on the parallel differences in thermal states between acclimatized *v* unacclimatized individuals and the early *v* late onset of vasodilatation, it was hypothesized that individuals showing an early CIVD response to local cooling would maintain higher hand skin temperatures during whole-body cold exposure and thus evidence less of a manual performance decrement under these conditions than individuals showing later or no vasodilatation. If this were found to be the case, a local cooling test could be used to predict manual performance capabilities in the cold.

A secondary purpose of the present experiment was to determine the differences, if any, in digital, back of hand, forearm, rectal, and mean weighted skin temperature responses to whole-body cooling of individuals who differed in their vasodilatation patterns during local cooling.

## 2. Method

*Subjects:* The subjects were 30 Army enlisted men who served as volunteer test subjects (Ss) in the Climatic Research Chamber Test Subject Platoon at the U.S. Army Natick Laboratories. The Ss were chosen from a larger number on the basis of scheduling considerations. They ranged in age from 19 to 23 with the average age being 21 years. Eighteen subjects had had previous whole-body cold exposure experience, 15 had previously performed some or all of the manual tasks used in the present study, and 14 had participated in hand cooling studies. The Ss were assigned to one of three groups on the basis of time to vasodilatation during the hand cooling tests. These three CIVD groups were:  $<450$  sec,  $450-900$  sec, and  $>900$  sec. There were 10 Ss per group.

*Apparatus:* A low temperature refrigerated water bath (American Instrument Co., Model D19680) was used for the local cooling test. Bath temperature was maintained at  $4.4^{\circ}\text{C}$  by a built-in, thermostatically-controlled refrigeration unit and the water was stirred automatically. The test was conducted in a temperature-controlled chamber maintained at  $26.7^{\circ}\text{C}$ , 50% R.H., with minimal windspeed. The S, dressed in shorts and socks, sat next to the water bath on a lounge chair which was adjusted to ensure that all Ss immersed their right hands in the water up to the same level, the styloid process of the radius. During immersion of the hand, the arm hung loosely over the foam-cushioned top side of the bath in an approximately vertical position. No contact was made with the sides of the bath.

During the hand cooling test, mean weighted skin temperature (MWST) was recorded in  $^{\circ}\text{F}$  every 30 sec on a Leeds-Northrup Speedomax Recording System from weighted values of temperatures measured by copper-constantan thermocouples placed at 10 points on the body surface (Iampietro 1961). Digital skin temperature was recorded from a copper-constantan thermocouple taped to the ventral surface of the distal phalanx of the index finger on each hand.

The digital temperature of the immersed finger was recorded on the Speedomax Recording System once every 17 sec, while that of the nonimmersed finger was recorded every 30 sec. Water bath temperature was also monitored by means of a thermocouple immersed in the bath and the thermocouple output was recorded once every 84 sec. Rectal temperature was measured using a thermistor catheter the output of which was displayed on a galvanometer and read every 30 sec.

The phase of the study involving whole-body exposure to a low and a control ambient temperature was conducted in a climatic chamber maintained at either 15.6° or -6.7°C, 50% R.H., with minimal windspeed (<1.12 m/s). The *S* wore standard army fatigues, army field jacket and field trousers with liner, pile cap, and army insulated boots. No handwear was worn. Skin temperatures from the middle and the little fingers of the right hand, the back of the right hand, the right forearm, and MWST were recorded in °F on the Speedomax Recording System. Rectal temperature was measured using a thermistor catheter and read every 180 sec from a galvanometer display.

The following six manual tasks were performed by the *Ss* during the whole-body exposure phase of the study: screw tightening (ST), Purdue pegboard assembly (PA), knot tying (KT), cord and cylinder manipulation (CC), Minnesota rate of manipulation placing (MP), and block stringing (BS). For the ST task, *S* was required to alternately tighten and loosen two vertically-mounted screws with a screwdriver. The PA task involved the construction of pin-washer-collar-washer assemblies. For the KT task, *S* tied one 'overhand knot and bight' on each of a number of strings hanging from the edge of a horizontal, rotatable disk. The CC test involved alternately stringing small cylinders on cord loops attached to a flexible base and intertwining the loops to form a chain with one cylinder mounted on each link. The MP task consisted of picking up circular blocks with the preferred hand and placing them in a wooden frame. For the BS task, *S* strung small blocks with holes through each face onto a needle and string.

Prior to testing, all *Ss* had five days of practice on each task at an ambient temperature of 23.9°C. All *Ss* had three trials per practice session on both the MP and the ST tasks. The number of trials per practice session on the remaining four tasks was varied according to *S*'s previous experience with the task, but each *S* had at least three trials on each task. A trial on the various tasks was defined as follows: three screws tightened and loosened, six assemblies constructed, 20 knots tied, five cylinders strung and five cord loops laced, 44 blocks placed, and 15 blocks strung.

*Procedure:* Prior to the initiation of the hand cooling test, thermocouples were attached to the right and the left index fingers and to ten points on the left side of the body. Each *S* inserted a rectal catheter. Recording was initiated during the 15 min pre-immersion period. The *S* then immersed his right hand in the water for 15 min and recording continued throughout the immersion and a 15 min post-immersion period.

A number of candidate *Ss* were run to obtain 10 *Ss* for each of the three CIVD groups. The groups were comprised of *Ss* who vasodilated in less than 450 sec after immersion of the hand in water (<450 group), who vasodilated in 450 to 900 sec (450-900 group), and who did not vasodilate within the 15 min immersion period (>900 group). Vasodilatation was defined as an increase

of at least 3°F (1.7°C) in the index finger temperature of the immersed hand (Teichner 1966).

Those *Ss* selected to continue in the experiment on the basis of scheduling availability then had five days of practice on the manual dexterity tasks followed by one session of whole-body exposure to cold and another session under the control ambient temperature condition. The order of exposure to the two temperature conditions was counterbalanced between *Ss*.

Each of the two whole-body exposure sessions was 3 hrs in duration, divided into six half-hour periods. During each period, *S* performed three consecutive trials on each of the manual tasks. The duration of a trial was 30 sec and the performance measure for each trial was the number of task components completed in that time. The order of task presentation was completely randomized within and between *Ss*. Approximately 20 to 25 min were required to perform all tasks comprising a period. During the remainder of the half hour, *S* was allowed to rest and to put his hands in the pockets of his field jacket. At the end of the half hour, the next period, with three more trials on each manual task, was begun. The physiological measures were recorded continuously during the time *S* was performing the tasks, but not during the rest break.

For the whole-body cooling exposure phase of the study, a separate analysis of variance was performed on the data of each manual task according to the following hierarchical design: *Ss* (1-10) by period (1-6) by ambient temperature (15.6°, -6.7°C) within CIVD group (< 450 sec, 450-900 sec, > 900 sec). The raw data for the task analyses were *S*'s mean scores, obtained by summing over the three trials on a given task within a period. With the exception of rectal temperature, the raw data of the physiological measures recorded during the whole-body exposure phase were means obtained over a *S*'s three trials on a task within a period. The MWST and the skin temperature of the right middle finger, the right little finger, the back of the right hand, and the right forearm were subjected to separate analyses of variance of the form: *Ss* (1-10) by task block (1-6) by period (1-6) by ambient temperature (15.6°, -6.7°C) within CIVD group (< 450 sec, 450-900 sec, > 900 sec). Task block refers to the division of a period into six tasks. Regardless of the task involved, these blocks were numbered consecutively to comprise the six levels of the task block variable. The raw data for the rectal temperature measure were the means for each period obtained by summing over the six task blocks. The analysis of variance for this measure was of the form: *Ss* by period by ambient temperature within CIVD group.

### 3. Results

#### 3.1. Local Cold Exposure

Figure 1 is a plot of the mean skin temperature of the right index finger of each CIVD group as a function of time during the three periods of the hand cooling phase. The mean pre-immersion temperature of the < 450 group was 35.0°C and the other two groups had a mean of 33.9°C. During the immersion and the post-immersion phases, the temperatures of the < 450 group remained highest at 6.7°C and 28.3°C, respectively. The 450-900 group had a mean of 6.1°C during immersion and 26.1°C during post-immersion, while the temperatures of the > 900 group were 5.6°C and 23.3°C for these two periods. The minimum temperature achieved by the < 450 group during local cooling was

5.6°C and the other two groups both had a minimum of 5.0°C. Vasodilatation to criterion occurred approximately 357 sec after water immersion for the <450 group, while the 450-900 group required approximately 663 sec. The rate of right finger temperature increase during post-immersion and the final level achieved differed distinctly as a function of CVD group (Figure 1).

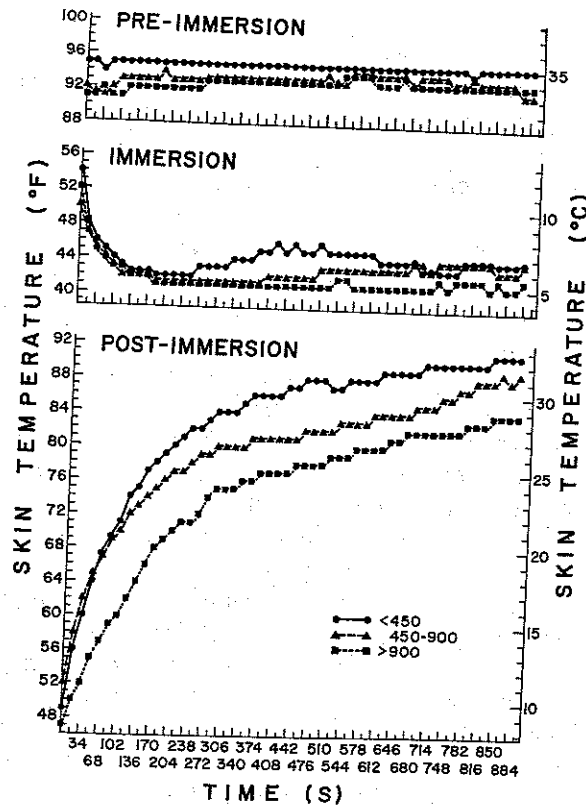


Figure 1. Mean skin temperature of the right index finger as a function of time, CVD group, and local cooling phase.

The mean skin temperature of the index finger of the left, or nonimmersed, hand for each CVD group is presented in Figure 2. Again, the <450 group maintained the highest temperature for each period with the mean being 34.5°C during pre-immersion and decreasing by 0.6°C during each of the subsequent periods. Prior to immersion, the index finger skin temperature of the non-immersed hand of the >900 group was 33.9°C and that of the 450-900 group was 32.8°C. The index finger skin temperatures of both the 450-900 and the >900 groups were 31.1°C and 30.6°C during immersion and post-immersion, respectively.

Those subjects whose immersed right index fingers vasodilated to criterion also reflected a 1.7°C increase in left index finger temperature after an initial vasoconstriction (Figure 2). Upon immersion of the right hand, the left index finger temperature levels of all three CVD groups initially decreased. The <450 group exhibited a 1.7°C rise from their minimum temperature in approximately 270 sec. The 450-900 group achieved this increase in approximately

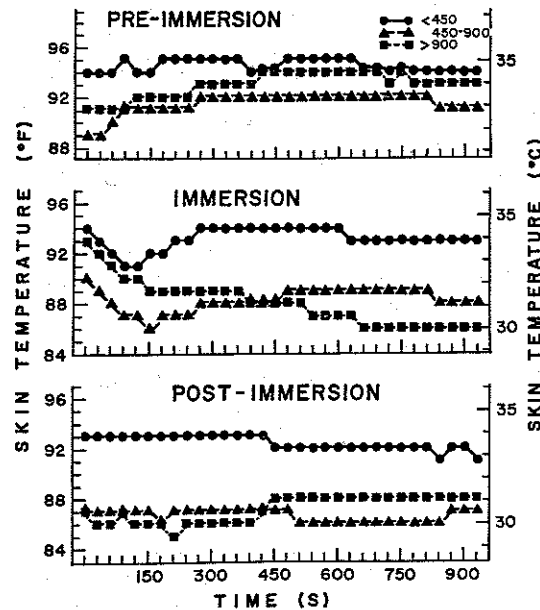


Figure 2. Mean skin temperature of the left index finger as a function of time, CIVD group, and local cooling phase.

480 sec. The surface temperature of the nonimmersed finger for the >900 group decreased over the immersion period.

Mean rectal temperatures and MWSTs per 5 min for each CIVD group and hand cooling period are presented in Table 1. In general, although the differences were small, the <450 group maintained the highest levels on these measures and the 450-900 group was lowest. The greatest rectal temperature decreases for each group occurred during the immersion phase.

Table 1. Mean Rectal Temperature and MWST ( $^{\circ}\text{C}$ ) of each CIVD group during local cooling

Measure	Pre-immersion			Immersion			Post-immersion		
	<450	450-900	>900	<450	450-900	>900	<450	450-900	>900
Rectal temperature									
5 min	37.53	37.36	37.53	37.42	37.31	37.47	37.25	37.14	37.20
10	37.53	37.36	37.47	37.42	37.31	37.36	37.25	37.08	37.14
15	37.47	37.36	37.47	37.31	37.20	37.31	37.20	37.08	37.14
MWST									
5 min	33.4	32.8	33.4	33.9	33.4	33.9	33.9	33.4	33.9
10	33.4	33.4	33.4	33.9	33.4	33.9	33.9	33.4	33.9
15	33.9	33.4	33.4	33.9	33.4	33.9	33.9	33.4	33.9

### 3.2. Whole-Body Cold Exposure

*Temperature data.* The middle finger, little finger, back of hand, forearm, and mean weighted skin temperature data obtained while the manual tasks were being performed during the whole-body cold exposure phase of this study were analysed. The main effects of ambient temperature, period and task block were significant. In general, surface temperatures decreased over periods, task blocks, and ambient temperatures. All first and second order

interactions involving these variables were also significant with the exception of the task block by period interaction in the analysis of the forearm data. For the task block by period interaction, the decrease in surface temperature across blocks was less after the first period. For those interactions involving ambient temperature, surface temperatures decreased as a function of task block or period more during exposure to the  $-6.7^{\circ}\text{C}$  than to the  $15.6^{\circ}\text{C}$  condition.

The sources of variance of particular interest in the analysis of the surface temperature measures are those involving CIVD groups. The CIVD group main effect was not significant for any of the skin temperature measures. The CIVD group by period interaction did approach significance ( $p < 0.10$ ) for the back of hand and the MWST measures. The only significant interaction involving CIVD group was that with task block for the middle and the little finger temperature data (Table 2).

Table 2. Significant effects from temperature and task analyses

Measure	Source of variance	df	Mean square	F	p
Back of hand	CIVD Group $\times$ Period	10/135	35.93/19.61	1.83	0.10
MWST	CIVD Group $\times$ Period	10/135	3.64/2.14	1.70	0.10
Middle finger	CIVD Group $\times$ Task Block	10/135	19.65/5.01	3.92	0.001
Little finger	CIVD Group $\times$ Task Block	10/135	21.97/10.48	2.10	0.05
Rectal	Ambient Temperature	1/21	5.40/0.26	20.77	0.001
	Period	5/105	0.14/0.04	3.50	0.001
	Ambient $\times$ Period	5/105	0.79/0.03	26.33	0.001
	CIVD Group $\times$ Ambient				
	$\times$ Period	10/105	0.09/0.03	3.00	0.001
Purdue assembly	CIVD Group $\times$ Period	10/135	13.70/6.35	2.16	0.05
Knot tying	CIVD Group $\times$ Period	10/135	9.95/4.68	2.13	0.05
Cord and cylinder	CIVD Group $\times$ Period	10/135	2.08/1.00	2.08	0.05

Mean back of hand surface temperatures and MWST are presented in Table 3 as a function of ambient temperature, CIVD groups and period. The CIVD group by period interaction for the back of hand surface temperature is reflected by the combined effect over ambient temperature of an increase in the  $> 900$  group surface temperatures across periods at  $15.6^{\circ}\text{C}$  and a relatively greater decrease across periods for the  $< 450$  group temperature data at  $-6.7^{\circ}\text{C}$ . For the MWST data, all CIVD groups showed comparable decreases

Table 3. Mean Skin Temperature ( $^{\circ}\text{C}$ ) of each CIVD group during whole-body exposure for each period

Measure	Period	Ambient temperature					
		$15.6^{\circ}\text{C}$			$-6.7^{\circ}\text{C}$		
Back of hand		$< 450$	450-900	$> 900$	$< 450$	450-900	$> 900$
	1	30.69	30.47	29.58	23.13	23.07	23.30
	2	30.75	29.91	30.08	17.85	18.74	17.85
	3	30.80	30.36	29.91	15.68	16.24	15.79
	4	30.75	30.30	30.14	14.23	15.57	15.12
	5	30.75	30.25	30.69	13.57	15.46	14.90
MWST	6	30.58	30.47	30.69	13.34	14.73	14.46
	1	32.36	32.36	32.92	29.80	29.91	30.14
	2	32.69	32.64	33.08	28.91	29.13	29.13
	3	32.80	32.69	33.03	28.63	28.69	28.63
	4	32.86	32.69	33.14	28.30	28.41	28.41
	5	33.08	32.64	33.25	28.13	28.13	28.30
	6	33.08	32.58	33.25	28.08	28.02	28.41

in surface temperature across periods at  $-6.7^{\circ}\text{C}$ , but the  $<450$  CIVD group showed a relatively greater increase in MWST across periods at  $15.6^{\circ}\text{C}$  than that shown by the other two groups.

Mean middle finger and little finger surface temperatures are presented in Table 4 as a function of ambient temperature, CIVD group, and task block. Averaged across ambient temperature and periods, the 450-900 group middle finger and little finger surface temperatures decreased more across task blocks than those of the other two groups. At  $-6.7^{\circ}\text{C}$ , initial 450-900 group surface temperatures were higher than those for the other two groups but reached a minimum temperature lower than that for the  $>900$  group and higher than that for the  $<450$  group. By the last task block, the 450-900 and the  $>900$  group surface temperatures were similar.

Table 4. Mean Skin Temperature ( $^{\circ}\text{C}$ ) of each CIVD group during whole-body exposure for each task block

Measure	Task block	Ambient temperature					
		$15.6^{\circ}\text{C}$			$-6.7^{\circ}\text{C}$		
		$<450$	450-900	$<900$	$<450$	450-900	$<900$
Middle finger	1	30.97	29.86	30.25	14.34	15.01	13.73
	2	30.58	29.19	30.02	12.62	13.23	12.57
	3	30.47	29.13	29.97	12.06	12.34	12.29
	4	30.52	29.25	29.91	11.62	11.90	12.18
	5	30.58	29.13	30.14	11.40	11.68	12.12
	6	30.52	29.25	30.36	11.34	11.84	11.84
Little finger	1	30.91	29.25	30.80	13.18	14.84	13.57
	2	30.47	28.74	30.58	11.12	12.18	11.73
	3	30.36	28.80	30.58	10.68	10.90	11.34
	4	30.30	28.69	30.75	10.45	10.68	11.40
	5	30.41	28.58	30.80	10.56	11.29	11.56
	6	30.47	28.80	31.08	10.79	11.62	11.56

For the rectal temperature measure, ambient temperature, period, and their interaction were significant (Table 2). At  $15.6^{\circ}\text{C}$ , mean rectal temperature was  $37.25^{\circ}\text{C}$  while, at an ambient temperature of  $-6.7^{\circ}\text{C}$ , it was  $37.14^{\circ}\text{C}$ . The significant period by ambient temperature interaction took the form of an increase in rectal temperature at  $15.6^{\circ}\text{C}$  from  $37.20^{\circ}\text{C}$  during period 1 to  $37.36^{\circ}\text{C}$  during period 6, and a decrease over periods from  $37.25^{\circ}\text{C}$  to  $37.03^{\circ}\text{C}$  at  $-6.7^{\circ}\text{C}$ . The period by ambient temperature by CIVD group interaction

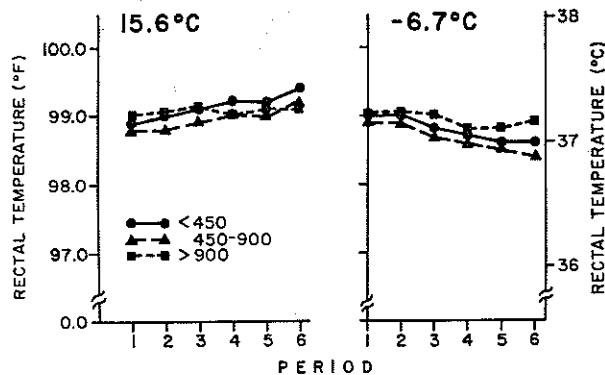


Figure 3. Mean rectal temperature as a function of CIVD group, period, and ambient temperature. ERG.

in the analysis of the rectal temperature measure was also significant (Table 2). Although both the <450 and the 450-900 groups showed parallel increases in rectal temperature over periods at the higher ambient temperature and parallel decreases at  $-6.7^{\circ}\text{C}$ , the >900 group maintained a relatively constant temperature level at  $15.6^{\circ}\text{C}$  and did not evidence the linear decrease at the lower ambient shown by the other groups (Figure 3).

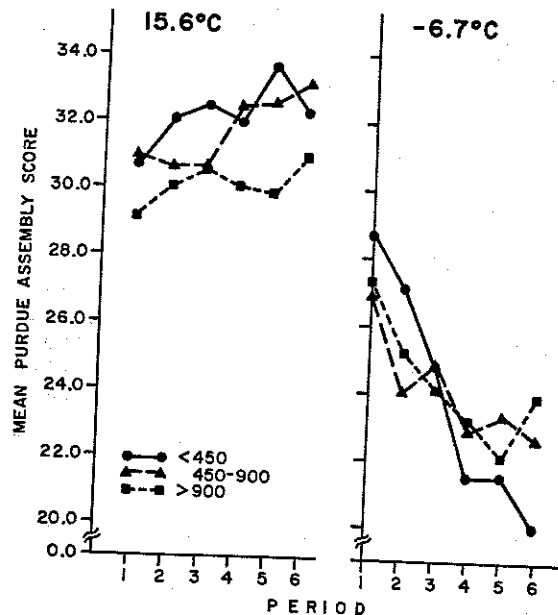


Figure 4. Mean Purdue Pegboard Assembly Test score as a function of CIVD group, period, and ambient temperature.

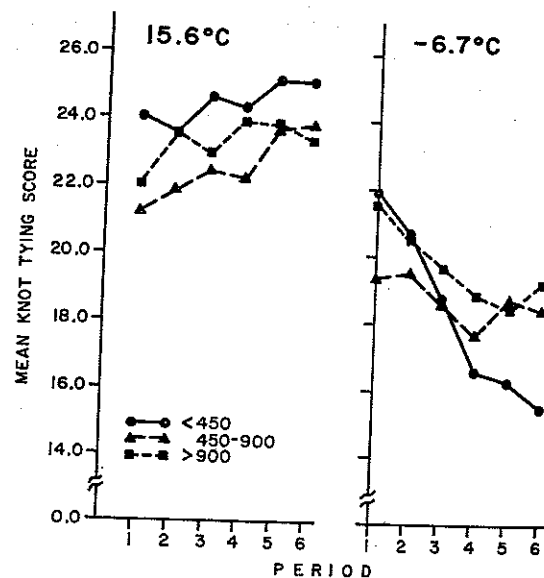


Figure 5. Mean Knot Tying score as a function of CIVD group, period, and ambient temperature.

*Task data.* With the exception of the period effect in the analysis of the MP task data, the ambient temperature effect, the period effect, and the ambient temperature by period interaction were significant in the analysis of each task. The significant ambient temperature effect was reflected in superior manual performance at 15.6°C relative to that at -6.7°C. The period main effect took the form of decreases in performance level between periods 1 and 6. The significant interaction between ambient temperature and period was reflected, generally, in a slight increase in performance scores for all tasks over periods at 15.6°C and a large decrease over periods in manual performance at -6.7°C.

The main effect of CIVD group was not significant. However, the CIVD group by period interaction was significant in the analysis of the PA, the KT, and the CC data (Table 2). The mean performance levels on the PA, the KT, and the CC tasks as a function of CIVD group, period, and ambient temperature are presented in Figures 4, 5 and 6, respectively. The principal aspect of the significant CIVD group by period interactions was that the <450 group, initially superior to the other two groups on these three tasks, obtained mean scores lower than or equal to those of the other groups by period 6. The performance level of each group decreased between periods 1 and 6 with the exception of the 450-900 group on the KT task and the >900 group on the CC task.

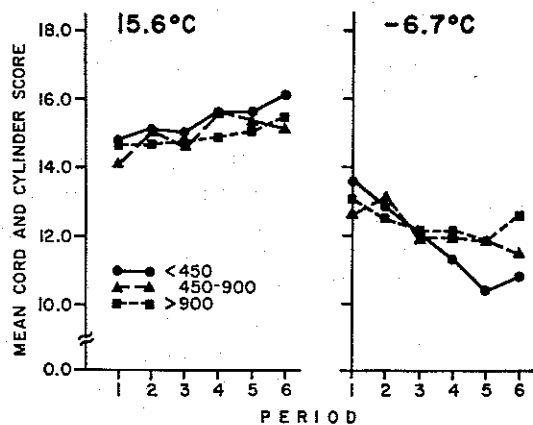


Figure 6. Mean Cord and Cylinder Test score as a function of CIVD group, period, and ambient temperature.

#### 4. Discussion

The results of the local cold exposure phase of the present study indicate that subjects categorized on the basis of time to vasodilatation during immersion of the hand in cold water also differ with regard to other temperature parameters. For instance, the shorter the latency to dilatation during local cooling, the faster the rewarming after removal of the hand from the water. In addition, subjects with a short latency to dilatation during local cooling (<450 sec) showed slightly higher digital, rectal, and mean weighted skin temperatures prior to water immersion than did those with a longer latency or absence of dilatation. Therefore, the inter-group relationships found here were similar to those reported by Teichner (1966) between a group which

vasodilated in less than 400 sec and those who showed no such response during a 10 min local cooling period. The CIVD response of the fast vasodilators also occurred at a slightly higher digital temperature than did that of the group with a longer latency, which is similar to the difference between Alaskan natives and unacclimatized Caucasians reported by Meehan (1957).

During immersion of the hand in cold water, there was an initial vasoconstriction of both the immersed and the contralateral hand. If subsequent dilatation occurred, it was reflected by a rise in the digital temperature of both hands with dilatation of the nonimmersed hand anticipating that of the immersed one. Those subjects whose immersed hands remained constricted gave no evidence of dilatation in the contralateral hand and, instead, evidenced a decrease in the temperature of the latter over the 15-min immersion period.

Based upon Teichner's (1966) finding that those subjects who dilated in less than 400 sec generally had slightly higher rectal and estimated mean skin temperatures than those who remained constricted during a 600 sec local cooling period, it might be expected that, in the present study, subjects who remained constricted during the 15 min of hand immersion would have lower rectal and mean weighted skin temperatures than those who vasodilated some time within the 15-min period. However, this was not the case. Although the subjects with an intermediate time to vasodilatation (450-900 sec) maintained higher digital temperatures than the non-vasodilators both during and after local cooling, the rectal and the mean weighted skin temperatures of the former group were lower before, during, and after local cooling. These temperature differences were small but seem to indicate that there is no direct relationship between time to vasodilatation and the levels of rectal and mean weighted skin temperature.

The relationships among the CIVD groups with regard to temperature responses during local cooling were not maintained during whole-body cold exposure. Neither digital temperatures nor body surface temperatures were affected directly by CIVD group or by the interaction of this variable with ambient temperature. Thus, in the present study, vasodilators did not evidence either the capability, found in acclimatized *v* unacclimatized individuals, of maintaining higher digital temperatures than non-vasodilators during whole-body cold exposure (Meehan 1957) or the higher body surface temperatures that Leblanc (1966) found for Gaspé fishermen and Eskimos in comparison with unacclimatized control subjects. Therefore, there was no evidence in the present study that those individuals showing an early onset of vasodilatation in response to local cooling will behave more like acclimatized subjects during whole-body cold exposure than individuals who show either a later onset or no vasodilatation during local cooling.

There was no indication of direct, cold-induced vasodilatation during whole-body cold exposure in the present study. However, this may be attributable to the fact that the skin temperature raw data were means obtained by summing over 30 sec intervals. Also the procedure whereby the subjects rewarmed their hands between periods might have obscured any observation of vasodilatation during whole-body cold exposure.

Manual performance on all six tasks was affected adversely when the subjects were exposed to a  $-6.7^{\circ}\text{C}$  ambient temperature and worsened with continued cold exposure. The drop in performance on three tasks involving

skilled movements of the wrist and the fingers over periods was greatest for the <450 group. In addition, there was a nonsignificant trend for this same group to show initially higher and then, by period 4, lower back of hand temperatures than those of the other groups.

In a study of the use of radiant heat at the work site to alleviate cold-impaired manual performance, Lockhart and Kiess (1971) found manual performance during cold exposure to be negatively correlated with surface temperature at the back of the hand (the lower the surface temperature, the longer it took to complete the task) and that the application of heat to the back of the hand was most successful in improving fine finger dexterity performance during cold exposure. It was assumed that warming the back of the hand acted to sustain subsurface temperatures in the fingers and that fine finger dexterity tasks are relatively more dependent upon the integrity of finger muscles, nerves, and joints than other aspects of manual performance. It is assumed further that the greater decrease in fine finger dexterity performance over periods for the <450 group in the present study is related to the slight differences in back of hand surface temperatures which reflect, in turn, an even greater presumed decrease in subsurface temperatures.

It should be realized that the criterion for differentiation of subjects into CIVD groups and the times to vasodilatation which defined the groups in the present study were arbitrary. Further experimentation focused on other parameters potentially involved with individual differences in vasodilatory responses is needed before more definite statements can be made regarding the relationships between CIVD and manual performance in the cold. Within the limits of the present study, the initially superior performance on specific manual tasks during whole-body cold exposure associated with the early onset of vasodilatation in local cooling *per se* becomes, with increasing durations of whole-body cold exposure, inferior to performance associated with the later onset or absence of vasodilatation in local cooling.

Cette étude se propose d'évaluer le degré de dextérité manuelle au cours d'une exposition à une ambiance froide, en fonction du délai d'apparition de la vasodilatation lors d'une réfrigération locale. Trente sujets de sexe masculin ont été répartis en trois groupes égaux en fonction du délai d'apparition d'une élévation de la température digitale (index) de 1°C lors de l'immersion de la main dans de l'eau à 4°C. Le premier groupe était composé de sujets présentant un délai <450 s; le deuxième de sujets présentant un délai compris entre 460 et 900 s et le troisième de sujets ayant des délais >900 s. Après cette répartition, chaque sujet a été exposé à une ambiance thermique de 15°C et de -6°C pendant 3 heures durant lesquelles il était soumis à une batterie de 6 épreuves manuelles à effectuer les mains nues. Les performances à toutes ces épreuves se sont détériorées lors de l'exposition à l'ambiance de -6°C et ont continué à se détériorer avec la prolongation de l'exposition. Les chutes des performances aux trois tâches impliquant des mouvements fins du poignet et des doigts étaient les plus importantes pour le groupe <450 s. Compte tenu des aspects limités de la présente étude, il semble que l'apparition précoce de la vasodilatation lors de la réfrigération locale soit associée à une performance initiale élevée suivie d'une performance moins bonne dans des tâches manuelles spécifiques en fonction de la durée de l'exposition totale à l'ambiance froide.

Diese Studie untersucht die Handgeschicklichkeit während einer Kälte-Aussetzung des ganzen Körpers als Funktion der Vasodilatationszeit während lokaler Abkühlung. 30 männliche Personen wurden auf drei gleiche Gruppen verteilt auf der Basis der Zeit einer 3°C-Zunahme der Zeigefinger-Temperatur während des Eintauchens der Hand in 4°C Wasser: <450 sec-Gruppe, 450-900 sec-Gruppe, und >900 sec-Gruppe. Danach wurde jede Person Umgebungstemperaturen von 15°C und -6°C für 3 Stunden ausgesetzt, während sie mit nackter Hand eine Batterie von sechs Handaufgaben ausführte. Alle Aufgaben mit Handarbeit wurden bei einer

Umgebung von  $-6.7^{\circ}\text{C}$  nachteilig beeinflusst und verschlechterten sich bei fortgesetzter Kälteeinwirkung. Der Leistungsverlust bei drei Aufgaben, die geschickte Bewegungen im Handgelenk und in den Fingern verlangten, war am grössten bei der  $<450$  sec-Gruppe. In der vorliegenden Studie scheint der frühe Eintritt der Vasodilatation per se mit anfangs erhöhter Leistung verbunden zu sein, der eine geringere Leistung bei spezifischen Handaufgaben bei wachsender Dauer der Kälte Wirkung auf den Gesamtkörper folgt.

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